COMPARISON OF SOFT TISSUE SIGNS VS COLD TEST AS INDICATORS OF PULPAL ANALGESIA DURING ENDODONTIC TREATMENT – AN IN VIVO STUDY.

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CERTIFICATE

This is to certify that this dissertation titled "**Comparison of Soft Tissue Signs Vs Cold Test as Indicators of Pulpal Analgesia during Endodontic Treatment – An In Vivo Study"** is a bonafide record of work done by **Dr. Riju Jacob Varghese** under my guidance and to my satisfaction during his postgraduate study period between 2009 – 2012. This dissertation is submitted to THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY, in partial fulfillment for the award of the degree of Master of Dental Surgery in Conservative Dentistry and Endodontics, Branch IV. It has not been submitted (partially or fully) for the award of any other degree or diploma.

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CONTENTS

Achieving profound pulpal anaesthesia is a corner stone in endodontic practice and dentistry. Adequate pulpal anaesthesia during root canal procedures benefits not only the patient, but also the dentist who will be less stressed worrying about patient reactions or sudden movements during therapy [37].

The failure to achieve sufficient anaesthesia can result from improper delivery, inappropriate type and amount of anaesthetic, presence of infection, unusual patient anatomy, patient anxiety, or a combination of any of these factors. Studies that have investigated the efficacy of certain techniques and/or types of anaesthetic solutions report that some have a more rapid onset, work better in the presence of an infection, last longer, and/or have fewer side effects [29, 30, 50]. However, regardless of the type or location of delivery, obtaining profound anaesthesia is the primary objective. Measuring the level of anaesthetic effect in patients prior to treatment is arguably more important than how or what is used to achieve anaesthesia [21].

Currently, there is no "gold standard" method to assess the level of anaesthetic effect. Traditional methods to confirm anaesthesia usually involve questioning the patient ("Is your lip numb"), testing soft tissue signs (e.g.: lack of mucosal responsiveness to a sharp explorer), or simply commencing with treatment and these have not been met with very promising results. These subjective signs are further complicated by the patient's interpretation of pain which is highly variable and depends on emotional and physiological states and past experiences. The problem with these approaches is that they may not be effective for determining pulpal anaesthesia [20, 28, 49]. A more objective measurement of anaesthesia in non-painful vital teeth is obtained by assessing the stimulation of nerve fibres with the application of a cold refrigerant or by using an electric pulp tester (EPT). Clinically, application of cold

or the electric pulp tester can be used to test the tooth under treatment for pulpal anaesthesia prior to beginning a clinical procedure [6, 11, 21, 24, 38].

The EPT excites A-delta fibres in the pulp through electrical stimulation. The pulp is assumed to be responsive or at least partially vital if a sensation is felt by the patient when a gradually increasing level of electrical current is transmitted through the tooth. EPTs vary in voltage range and amperage output. For instance, the EPT developed by Analytic Technology® (Redmond, WA) has a voltage range of 15 to 300 V and an amperage output of 0.50 µA. This EPT has a scale from 0 to 80 units, with an 80/80 reading that indicates maximum amperage output. There are several different manufacturers of EPTs. No available study has conclusively found one brand to be more effective than another [22, 35].

The cold test has many forms of delivery, such as ice sticks, carbon dioxide snow and refrigerant sprays. Due to its ease of storage, relatively cheap cost, and simple application technique, refrigerant spray is widely used in clinical settings. More effective agents such as dichlorodifluoromethane (DDM) have superseded traditional refrigerants such as ethyl chloride [7]. However, DDM being a chlorofluorocarbon has decreased in popularity and market availability due to environmental concerns of atmospheric ozone layer depletion [32]. Consequently, manufacturers replaced DDM with gases like 1, 1, 1, 2-tetrafluoroethane (TFE) [Green Endo-Ice® (Hygenic Corp, Akron, OH)] [24], but today even this is being phased out due to environmental regulations concerning the sale of Greenhouse gases and global warming potential. This has led to the introduction of a new blend of propane/butane/isobutene gas mixture stored in a pressurised canister [Hygenic Endo-Ice F® (Coltene/Whaledent GmbH, Langenau, Germany)] to serve as the new generation refrigerant sprays [7]. The cold test most commonly uses the Endo-Ice F, as other cold tests are currently not available commercially because of environmental reasons or difficulty with use. Each cold test varies by temperature. Ethyl chloride, Green Endo-Ice, DDM and Endo-Ice F are

roughly -10°C, -26°C, -50°C, and again -50°C respectively [38]. Endo-Ice F is easy to use, with rapid results. A bright A-delta sensation or cold response felt by the patient indicates that part or all of the pulpal tissue is responsive.

The hydrodynamic theory of pulp sensitivity suggests that electrical stimulation and cold stimulation have two different mechanisms of action. According to this theory, cold may cause neurons to act as mechanoreceptors that react to movement from the thermal contraction of dentinal fluid. On the other hand electrical stimulation causes depolarization of nerve membranes by ionic shifts [39].

Heat tests also have many methods of delivery, such as warm guttapercha, isolating a tooth with a rubber dam and adding warm or hot water to create a bath, or warming with a heat carrier. Heat tests are infrequently performed because of difficulty with tooth isolation and/or obtaining a consistent heat stimulus [22, 35].

Petersson et al [41] conducted a comprehensive study evaluating the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of cold (ethyl chloride) and hot (warm gutta-percha) tests and EPT. They assessed 65 patients using all three tests and compared the test results with clinical findings of pulpal status upon accessing the pulpal chamber. Their results showed that the cold test using ethyl chloride scored better than the electrical and heat tests at predicting pulpal vitality. **Bjorn** [4] was the first to correlate a negative response to an 80/80 EPT reading with painless care during dental treatments. Very few studies thereafter have used the EPT or cold test as a measure of anaesthesia and then followed through with dental treatment to assess whether the patient was sufficiently anesthetized to experience dental care without pain.

The aim of this study was to determine whether the cold test can better assess if a patient will experience pain during root canal therapy compared with the current standard of care using patient-reported soft tissue signs as a measure of local anaesthetic efficacy.

Harris SC and Blockus LE [18] (1952) studied the analgesic effectiveness of 65 mg of codeine phosphate by comparing the difference observed between pre-medication and post-medication thresholds with similar data obtained from the same subjects on another occasion when placebos were used. Their objective was to evaluate quantitatively the reliability and validity of electrical excitation of the human tooth pulp as an algesimetric method. They concluded that evidence of reliability was obtained by finding that no significant differences occurred between the thresholds of experimentally induced pain when measured in 28 teeth, three times in immediate succession and the validity of the method was partially attested finding that 65 mg of codeine significantly elevated the threshold above the average pre-medication level, above the average threshold when no treatment was given and above the average threshold after placebos.

Harris SC [19] **(**1956) commented that if a compound relieves clinically occurring pain, it need not necessarily elevate the pain threshold, but if a compound elevates the pain threshold, it should relieve clinically occurring pain. He stated that there is no single, completely adequate method for evaluating analgesics. Common to all methods is some degree of quantitative evaluation of the change in relationship of response to stimulus before and after administration of the drugs being investigated. In animal and human laboratory studies, usually the stimulus intensity or duration is varied to elicit a uniform degree of response. In clinical algesimetry, either the dose of analgesic drugs necessary to obtund clinically occurring pain, or the incidence of relief after certain doses is determined. Consequently, placebo medication and the "double blind" regimen have become almost standard. His report concluded that tooth pulp algesimetry affords reliability and reasonably good validity.

Topazian RG [47] **(**1957) authored a text on pain thresholds and the factors that modify them. He stated that the pain threshold stimulus is the amount of stimulus which, on the average, is required to evoke the pain threshold and this intensity of stimulus should be measurable in standard physical units. Mechanical, chemical and thermal methods were used to conduct a study in this manner. He studied several factors like cultural and racial factors, fatigue, psychological makeup, emotional security, distractions, attitude and mood. He concluded that all of these factors play an important part in the patient's reaction to any pain or anticipated pain and thus to his pain experience.

Dachi SF [10] (1967) performed a study for standardization of a protocol for dental sensitivity to cold. The results of this study revealed certain interesting findings. First, the number of teeth responding positively to a cold test did not increase significantly when the stimulus was left on the tooth beyond 5 to 8 seconds. There was also a high degree of statistical correlation between the teeth which were bothersome to the patient when biting ice cream and those which responded positively to the cold test. Finally, the results of these tests proved to be useful for standardizing measurements in future studies in this aspect and also for their comparison with those of other investigators.

Mullaney TP [34] (1970) studied the resistance of nerve fibres to pulpal necrosis. They concluded that it was unlikely that nerve fibres resist necrosis as had been speculated in the past and hypothesised that the pain response of the patient is most likely due to the movement or compression of the necrotic pulp and the resultant pressure on the periapical tissues.

England MC et al [13] (1974) did a histopathologic study of the effect of pulpal disease upon nerve fibres of the human dental pulp. Intact fibres with some variation from normal

were observed in the specimens with irreversible pulpitis. The degeneration appeared to be less severe, however, than that of surrounding tissue. These nerve fibres remained essentially intact and appeared to be capable of conduction. They concluded that these nerve fibres resist degeneration longer than the surrounding tissue. At some point, however, as irreversible pulpitis progresses into necrosis, degeneration and dissolution of the nerve fibres was apparent. Only connective tissue sheaths remained and conduction of a nerve impulse was considered impossible in these specimens.

Fulling H J and Andreasen J.O [14] (1976) studied the influence of maturation status and tooth type of permanent teeth upon electrometric and thermal pulp testing. Their study showed that until completion of root formation teeth show an increased electrometric threshold value. The carbon dioxide snow was the most reliable method examined, giving a consistent positive response in all examined teeth.

Fulling H J and Andreasen J.O [15] (1976) studied the influence of splints and temporary crowns upon electric and thermal pulp-testing procedures. The results of this study indicated that both electrometric and thermal pulp testing procedures could be carried out in the presence of different splints or temporary crowns. However, if the tooth was totally covered by a stainless steel crown only carbon dioxide snow showed a consistent response.

Ehrmann EH [12] (1977) reviewed pulp testers and pulp testing with particular importance to the use of dry ice. He stated that pulp testing is mandatory before any operative procedures, invaluable in the diagnosis of pain and is an essential adjunct in the interpretation of radiolucent areas. Various methods of pulp testing available during that time and the use of dry ice for this purpose was discussed in detail. Limitations of pulp

testing were also considered. He also said that vitality tests were of only limited use in traumatized teeth and that its results were only qualitative and not quantitative. He concluded that vitality tests cannot be considered absolute in themselves but must be interpreted in conjunction with a thorough clinical examination.

Trowbridge HO et al [48] (1980) investigated the sensory response of natural teeth to thermal stimulation. The results of the study indicated that sensory response to thermal stimulation occurred before there was a temperature change in the region of the pulpodentinal junction where sensory endings are located. They concluded that the sensory response is not initiated by temperature changes occurring in the receptors. A theoretical model was developed to examine the hydrodynamic forces that may have been produced by temperature changes occurring within the dentin. These forces, although small, could have been capable of initiating generator potentials within the nerve endings by displacing the surface membranes of the sensory receptors.

Malamed SF [27] (1981) attempted to relate the effectiveness of the Gow-Gates technique for mandibular anaesthesia and its potential advantages and disadvantages compared the conventional inferior alveolar nerve block. The advantages he listed include single injection, decreased positive aspiration rate; fewer post injection problems and a greater success rate. The only disadvantage he noted was the slower onset of anaesthesia. He concluded that the Gow-Gates technique could be described as a more successful technique with less risk of adverse side effects.

Augsburger RA and Peters DD [2] (1981) compared the in vitro effects of ice, skin refrigerant, and CO_2 snow on intrapulpal temperature. Their results showed that a five second

CO_2 snow application resulted in a statistically greater intrapulpal temperature decrease than ice or skin refrigerant in both noncarious and crowned teeth. They concluded that in contrast to ice and skin refrigerant, the effectiveness and superiority of the CO_2 pencil for testing crowned teeth were clearly demonstrated by their study.

Montagnese TA et al [33] (1984) compared the effectiveness of the Gow-Gates technique and the standard inferior alveolar nerve block technique in attaining mandibular anaesthesia. The results demonstrated no significant differences between the two injection techniques. Both injection techniques achieved a high percentage (98%) of patient perceived overall numbness and lip numbness. Objective testing showed that only 38% of the subjects that received the standard injection and 35% of the subjects in the Gow-Gates technique gave no response to the electric pulp tester at the maximum output (80/80).

Wallace JA et al [50] (1985) conducted a pilot study to assess the clinical problem of regionally anaesthetizing the pulp of an acutely inflamed mandibular molar. In the study, the mandibular nerve of a cat under general anaesthesia was isolated and then regionally blocked. A stimulating electrode was implanted in a cuspid tooth and a receiving electrode in the cortex of the brain. When a state of inflammation was created in the tooth in the presence of a regional block, there was an increasing cortical response to this stimulation. The nature of these changes is such that the reduction in ion flow and in action potential created by local anaesthetic agents is not sufficient to prevent impulse transmission for the reason that the lowered excitability threshold allows transmission, even under conditions of anaesthesia. They concluded that patients do indeed experience pain in inflamed pulps, even when a regional anaesthetic block has been given.

Fuss Z et al [16] (1986) determined the accuracy of CO_2 snow and Dichlorodifluoromethane (DDM) in comparison to electric, thermal pulp vitality tests, ethyl chloride and ice in vivo. They also assessed the degree of temperature change occurring in the region of the pulpodentinal border zone, following the application of cold testing agents to the tooth surface in vitro. Their results indicated that the electric pulp test, CO_2 snow, and DDM were equally reliable in producing a positive response in the teeth of older individuals. However, in the younger age group the electric pulp test was significantly less effective than CO_2 snow and DDM. The electric pulp test, DDM, and CO_2 snow were all more dependable than either ethyl chloride or ice. The cold testing agents applied to teeth in vitro indicated that CO_2 snow and DDM produced an appreciably greater decrease in temperature in the pulpodentinal border zone when compared to either ethyl chloride or ice.

Dreven LJ et al [11] (1987) conducted a study to evaluate clinical analgesia in normal, asymptomatic, and symptomatic human vital teeth using the Analytic Technology electric pulp tester. Their results showed that the normal and asymptomatic groups had analgesia 100% of the time whereas in the teeth with irreversible pulpitis only 73% had clinical analgesia. They concluded that the Analytic Technology pulp tester can be a valuable clinical aid to the practicing dentist, since it enables the practitioner to monitor, objectively, the course of anaesthesia in normal and asymptomatic teeth.

Mikesell A et al [31] (1987) compared the analgesic efficacy of 1.8 ml and 3.6 ml of 2% lidocaine with 1:100,000 epinephrine in human maxillary infiltration injections with the use of an electric pulp tester. It was concluded that successful pulpal anaesthesia was attained within 7 minutes and continuously sustaining the anaesthesia was significantly better with 3.6ml per volume of anaesthetic agent.

Rickoff et al [43] (1988) studied the effects of thermal vitality tests on human dental pulp. Histological evaluation of the pulps of premolar teeth to which heated gutta-percha had been applied for up to 10 s revealed no evidence of injury and teeth to which carbon dioxide (CO_2) snow was applied for as long as 5 min were found to have structurally intact pulps. When the thermal testing agents were applied to teeth in vitro, temperature in the region of the pulpodentinal junction did not reach noxious levels. They concluded that assessment of tooth vitality with either heated gutta-percha or CO_2 snow does not jeopardize the health of the pulp.

Vreeland DL et al [49] (1989) evaluated the anaesthetic efficacy of 1.8 ml of 2% lidocaine with 1:100,000 epinephrine, 3.6 ml of 2% lidocaine with 1:200,000 epinephrine, and 1.8 ml of 4% lidocaine with 1:100,000 epinephrine in human inferior alveolar nerve block using the electric pulp tester. Their results showed that increasing the volume or concentration of lidocaine did not significantly increase the success of pulpal anaesthesia. It was concluded that no significant differences in anaesthetic success or failure were found among the three solutions and that the electric pulp tester could be a valuable clinical aid to assess the effect of anaesthesia in normal and asymptomatic teeth.

Hinkley SA et al [20] (1991) measured the degree of anaesthesia obtained with 4% prilocaine with 1: 200,000 epinephrine and 2% mepivacaine with 1:20,000 levonordefrin compared with 2% lidocaine with 1: 100,000 epinephrine for inferior alveolar nerve block using the Analytic Technology pulp tester. Their results showed that no statistically significant differences existed in onset, success, failure, or incidence among the solutions. It was concluded that all three solutions were equivalent in blocking the inferior alveolar nerve.

Roy M and Narahashi T [44] (1992) studied the electrophysiological properties of tetrodotoxin-sensitive (TTX-S) and tetrodotoxin-resistant (TTX-R) sodium channels in rat dorsal root ganglion neurons. They also examined the interactions of TTX, saxitoxin (STX), divalent cations, and lidocaine with these channels and found that each of these agents exerted differential effects on TTX-R and TTX-S channels. Their results showed that while TTX-S current was more sensitive to resting lidocaine block, TTX-R current was seen to be more susceptible to use dependant lidocaine block. They concluded that the biophysical and pharmacological properties of these two types of sodium channels were of particular importance in the development of the CNS and in the mechanism of action of drugs on the CNS neurons.

Mc lean et al [28] (1993) measured the degree of anaesthesia obtained with 4% prilocaine and 3% mepivacaine compared with 2% lidocaine (1:100,000 epinephrine) for inferior alveolar nerve block using the Analytic Technology pulp tester. It was concluded that all three solutions were equivalent in blocking the inferior alveolar nerve and that successful pulpal anaesthesia was more likely to occur in the first molar and first premolar than in the lateral incisor.

Pantera EA et al [39] (1993) determined whether the sequence and interval between electric pulp testing and cold pulp vitality testing with dichlorodifluoromethane (DDM) affects the reliability of pulpal diagnostic testing. The results indicated that all the teeth continued to respond to the EPT at all intervals after the use of dichlorodifluoromethane. It was thus concluded that electric pulp testing was not adversely affected by the use of dichlorodifluoromethane (DDM).

Cohen HP et al [8] (1993) compared the anaesthetic efficacy of 3% mepivacaine against 2% lidocaine with 1:100,000 epinephrine by using a dichlorodifluoromethane (DDM) cold test. They also assessed the value of the DDM cold test in determining pulpal anaesthesia and the effectiveness of the supplemental PDL injection of 2% lidocaine with 1:100,000 epinephrine. The results showed that 3% mepivacaine HCI is as effective as 2% lidocaine HCI in achieving pulpal anaesthesia in mandibular molars with IANB. Additional PDL injections were necessary in 38% of the cases to achieve a negative response with DDM even after the presence of successful lip anaesthesia. It was thus concluded that successful lip anaesthesia does not necessarily indicate successful pulpal anaesthesia and that the use of DDM can be considered as a reliable method of determining true pulpal anaesthesia.

Peters DD et al [40] (1994) compared false positive and false negative responses in both electrical and cold thermal pulp testing and determined if there was a correlation of these responses that could further increase the probability of identifying irreversibly involved pulps. The teeth were tested using CO_2 snow and 2 electric pulp testers. It was concluded that if an adult untraumatized tooth did not respond to CO_2 cold and an electrical test, then the pulp is almost certainly diseased or the tooth is pulpless. If teeth did not respond to cold and responded at readings greater than the tissue response to electrical, then there existed a high probability that the pulp was diseased and required further testing. The only diseased or pulpless teeth that responded to cold were multirooted teeth with a high probability of having viable tissue remaining. Also if the false positive responses to electrical that responded at levels higher than the patient's tissue response were considered to be negative responses, then the differences in false positives between cold and electrical were not statistically significant.

Certosimo AJ, Archer RD [6] (1996) conducted a study to evaluate the ability of the electric pulp tester to predict the efficacy of local anaesthesia prior to an operative procedure. They concluded that Analytic Technology electric pulp tester was an accurate predictor of the level of clinical pulpal anaesthesia and that soft tissue signs of anaesthesia were not reliable indicators of local anaesthesia.

Reisman D et al [42] (1997) studied the anaesthetic efficacy of supplemental intraosseous injection of 3% mepivacaine in irreversible pulpitis. They concluded that for mandibular posterior teeth with irreversible pulpitis, a supplemental intraosseous injection of 3% mepivacaine increased anaesthetic success and a second intraosseous injection, when necessary, further improved success.

Nusstein J et al [38] (1998) determined the anaesthetic efficacy of a supplemental intraosseous injection of 2% lidocaine with 1:100,000 epinephrine in teeth diagnosed with irreversible pulpitis. It was concluded that the supplemental intraosseous injection of 2% lidocaine with 1:100,000 epinephrine was a successful technique that could be used when inferior alveolar nerve blocks and maxillary infiltrations in posterior teeth diagnosed with irreversible pulpitis fails.

Meechan JG [29] (1999) reviewed about the various techniques that could be used to overcome unsuccessful local anaesthetic administrations. He stated that local anaesthetic failure is an unavoidable aspect of dental practice and that factors contributing to the failure can be related to either the patient or the operator. The author suggests the use of alternative approaches, like the Gow-Gates or Akinosi techniques, as an adjunct to the conventional inferior alveolar nerve block technique. He also suggests use of the intraligamentary,

intraosseous and intrapulpal techniques to alleviate the failure of pulpal analgesia. He concludes that adhering to a set of protocols for managing failed local anaesthesia, based on an understanding of the reasons for failure, could help overcome most cases encountered in practice.

Petersson K et al [41] (1999) evaluated the ability of cold test (ethyl chloride), heat test (hot gutta percha) and electric pulp test to register pulp vitality and then calculated the sensitivity, the specificity, the negative predictive value (NPV) and the positive predictive value (PPV) by comparing the test results with a gold standard which was established by direct pulp inspection of the teeth in need of endodontic treatment. The results from this study indicated that the probability for a non-sensitive reaction to represent a necrotic pulp was 89% with the cold test, 48% with the heat test and 88% with the electrical test. The probability that a sensitive reaction represented a vital pulp was 90% with the cold test, 83% with the heat test and 84% with the electrical test. They concluded that the cold test was a better indicator for pulp vitality when compared to the electric pulp test which in turn was a better indicator than the heat test.

Jones DM [23] (1999) evaluated the temperature changes produced within the pulp chamber after applying Dichlorodifluoromethane (DDM) in a spray or liquid form to the surface of a tooth using four different applicators which were #2 cotton pellets (large), #4 cotton pellets (small), wood handle cotton-tip applicators, and cotton rolls. It was concluded that the large cotton pellet #2 produced the coldest temperatures inside the pulp of the tooth by a range of 35.0 ° to 45.0°C. There was no significant difference between directly spraying and submerging the applicator in DDM liquid.

Meechan JG [30] (2002) reviewed the supplemental routes of anaesthesia, techniques that could be employed to achieve pulpal anaesthesia for endodontic procedures when conventional approaches have failed. The author suggests that intraligamentary, intraosseous anaesthesia and the intrapulpal approach are useful when conventional techniques fail as all have been shown to increase the incidence of pulpal anaesthesia when used in combination with standard technique of inferior nerve block. He also suggested the use of intraoral transcutaneous electronic nerve stimulation (TENS) to decrease the discomfort of inferior alveolar nerve block injections compared to the use of topical anaesthetics and no pre-treatment.

Jones VR et al [24] (2002) conducted a study to compare the accuracy of carbon dioxide (CO_2) dry ice sticks versus refrigerant spray (RS) to generate a patient response from different types of teeth restored to varying degrees. They concluded that RS and CO2 were equivalent in determining pulpal responsiveness, but the elicited response from RS was faster.

Miller SO et al [32] (2004) measured the temperature change occurring at the Pulp-dentin junction (PDJ) of extracted premolars restored with porcelain fused to metal (PFM) or all-porcelain full-coverage restorations compared with non restored premolars or those restored with full gold crowns during thermal testing with an ice stick; 1,1,1,2-tetrafluoroethane (TFE) or CO_2 snow. The results indicated that application of TFE on a saturated #2 cotton pellet was the most effective method for producing a temperature reduction at the PDJ of intact teeth. They concluded that TFE appeared to be the best method for cold-testing non-restored teeth and those restored with PFM or all-ceramic restorations for as long as 30 seconds, and for full gold crowns tested for less than 15 seconds.

Hsiao-Wu GW et al [21] (2007) undertook a study to determine if a negative response to cold testing was a more effective measure to assess pulpal anaesthesia compared to soft tissues signs alone, using a randomized, blinded, placebo-controlled design. They concluded that subjects who achieved a negative response to the cold test were approximately 80% less likely to experience pain during RCT compared to subjects with soft tissue signs of anaesthesia alone.

Chen E and Abbott PV [7] (2009) reviewed the pros and cons of the dental pulp testing. They stated that pulp sensibility testing, even with its limitations and short comings, have been and will remain a very helpful aid in endodontic diagnosis .They discussed about the thermal and electric pulp sensibility tests which extrapolates pulpal health from the sensory response. They suggested that the true measure of the vital pulp was to examine the pulpal blood flow rather than the sensibility and described the techniques of laser doppler flowmetry and pulse oximetry. It was concluded that the results from any of these various pulp tests need to be carefully interpreted and closely scrutinised as false results can lead to misdiagnosis which can then lead to incorrect, inappropriate, or unnecessary treatment.

Nusstein JM et al [37] **(**2010) reviewed various local anaesthesia strategies for patients with irreversible pulpitis with spontaneous, moderate-to-severe pain. They suggested that determination of adequate pulpal analgesia in teeth with irreversible pulpitis is of prime importance prior to endodontic procedures. The article impresses the fact that to deal with the eventual failures found with the IANB injection the clinician must incorporate electrical/thermal pulp vitality tests and supplemental anaesthesia techniques into his daily repertoire of skills. These additions in daily practice will provide the dentist with confidence to enable relatively pain-free treatment for the patient having a hot tooth.

ARMAMENTARIUM

- ***Instruments used***

a. Mouth mirror

b. Tweezers

c. Cow-horn Pig-tail Explorer

d. Long Shank Endodontic Excavator

e. DG -16 Endodontic Explorer

f. Spoon Excavator

g. Plastic Instrument

h. Contra-angled airotor handpiece (W&H High Speed Handpiece Press type, Model TC-95RM, Austria.)

i. Disposable Luer Mount syringe (DispoVan® 2ml syringe, Hindustan Syringes and Medical Devices Ltd., India.)

j. Dental Rubber Dam Kit (Hygenic® Coltene/Whaledent Inc., Mahwah, NJ, USA.)

k. BR-46 Round diamond abrasive (Dia-Burs, Mani, Japan.)

l. Safe end Bur (Endo Z, Dentsply Maillefer, Switzerland.)

m. Barbed broaches (#15 to #40, Mani, Japan.)

n. K Files (#15 to #40, Mani, Japan.)

o. H Files (#15 to #40, Mani, Japan.)

p. Glass slab

q. Cheek retractor

Fig. 1: Instruments used

- ***Materials used***

a. #2 Dental Cotton Rolls (Coltene Whaledent Pvt. Ltd., India.)

b. #2 Roeko® Dental Cotton Pellets (Coltene Whaledent Pvt. Ltd., India.)

c. Hygenic Endo-Ice F® (Coltene/Whaledent GmbH, Langenau, Germany.)

d. Lidayn® Lidocaine Topical Aerosol Spray (Midas-Care Pharmaceuticals Pvt. Ltd., Aurangabad, India.)

e. Lignox® 2% with adrenaline 1: 80000 local anaesthetic (Indoco Remedies Ltd., Goa, India)

f. 3% Sodium Hypochlorite (Vensons India Pvt. Ltd, Bangalore, India)

g. Normal saline (Baxter India Pvt. Ltd, Tamilnadu, India)

Fig. 2: Materials used

A double blinded, two-arm, randomized, placebo-controlled, clinical trial assessing the efficacy of using the propane/butane/isobutene gas mixture cold test for pulp vitality to measure profound anaesthesia during RCT, compared to patient-reported soft tissue assessment was intended. The presence of subjective soft tissue signs is currently the standard of care in evaluating the onset of local dental anaesthesia [11].

Sample size estimation

The sample size estimation was extrapolated from previous studies by **Dreven et al** [11], **Certosimo and Archer** [6], and **Cohen et al** [8]. The primary endpoint was the difference (delta, Δ) in the proportion of control subjects that experienced pain during root canal therapy minus the proportion of test subjects that reported pain. Using weighted averages, the estimated delta was 0.18 (0.25-0.07) based on these studies [11, 8]. A total of 128 subjects (64/study arm) was estimated to detect a difference of pain experienced by subjects with a power of 80%, using a two-sided test ($p = 0.05$) between the control/placebo and cold test arms. **Certosimo and Archer** [6] assessed pain experienced during operative treatment versus endodontic therapy; applying their data to estimate our sample size was conservative.

Major ethical concerns

Potential risks or discomfort to the subjects were no different than those of standard RCT. The consent form for this followed the guidelines of the Indian council of medical research. Patient confidentiality was maintained. The study was approved by Sri Ramakrishna Medical Hospital/ Sri Ramakrishna Dental College and Hospital Institutional review board.

Study Design and Schema

The study population consisted of patients that were treated by the post graduate students and faculty of the Sri Ramakrishna Dental College and Hospital. Subject inclusion criteria were as follows: adult status (> 18 years old), able and willing to sign a consent form, not currently enrolled in another clinical trial, not pregnant and not taking any medications

that would alter pain perception. The subjects had no contraindications to 2% lidocaine with 1:80,000 epinephrine or to the injection technique being used and had a study tooth that was responsive to the cold test at baseline. All study teeth considered were diagnosed with irreversible pulpitis having no visible periradicular changes.

Each subject was taught to distinguish between pressure and pulp sensitivity when the vitality testing agent was applied to his or her teeth and were instructed to raise one of their hands the moment they experienced a reaction to the test [16]. All patients were subjected to cold test to confirm baseline responsiveness. The tooth was isolated with cotton rolls and then air dried. The cold test was done by spraying the refrigerant on a #2 cotton pellet from a distance of 5 mm for a period of 3 sec, thus saturating the pellet [23]. Excess was shaken off and after crystals appeared on the surface, the pellet was placed on the midfacial surface of the concerned tooth. Responses were scored as responsive or nonresponsive. Responses were scored as nonresponsive when 15 s or more elapsed before the subject raised their hand [16, 40].

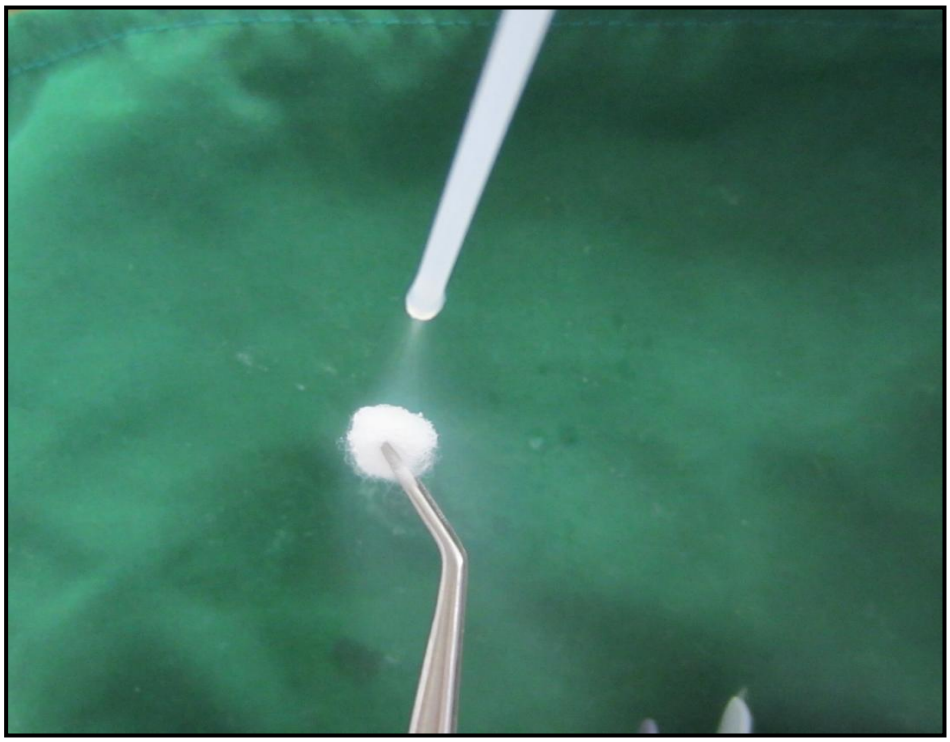

Fig. 3: Saturating the cotton pellet with the refrigerant spray

Fig. 4: Performing the cold test to determine baseline response

The subjects who fulfilled the inclusion and exclusion criteria were randomly selected for either a true cold test (test group) or a sham cold test (control group). After baseline cold testing, the primary investigator administered local anaesthesia to the patients and performed either the cold test or the sham test and then sent the patient to the clinician who was asked to perform standard RCT. Thus the clinician and the patient were blinded to the randomization arm of the subject.

Anaesthesia was administered by giving 1.8 ml of 2% lidocaine with epinephrine using a standard disposable 2ml dental aspirating syringe. In the mandible the inferior alveolar technique as described by **Monheim** [3] and modified by **Hayden** [25] was used. An additional one fourth of a cartridge was injected for anaesthesia of the long buccal nerve.

Mandibular anteriors, cuspids and bicuspids were given another 1 ml as infiltration. Maxillary molars, premolars, cuspids and anteriors received 1.8 ml of anaesthetic as infiltration on the facial aspect and another 0.2 to 0.3 ml as a palatal infiltration [6]. After injection of the anaesthetic agent a waiting period of five minutes for maxillary teeth [31] and fifteen minutes for mandibular teeth [49] was observed prior to evaluating each patient for subjective or objective signs of clinical anaesthesia. These times were reported by **Mikesell et al** [31] and **Vreeland et al** [49] as the optimum time required in achieving profound anaesthesia of the respective arches. The subjective signs consisted of facial gingival anaesthesia on maxillary teeth and lower lip numbness on the anaesthetised side of mandibular teeth [18].

Fig. 5: Administering the IANB

For the test group, standard RCT was performed after subjects were given sufficient local anaesthetic to achieve a negative response to the cold test using the Endo-Ice F. Cold test was performed as described earlier. A negative response was recorded when no response

was evoked after two successive 15 seconds application of the agent. Several minutes were allowed to elapse between the successive cold tests as previous studies [16] have shown that it may take up to two minutes for the pulpal border of the dentin to return to normal temperature following application of cold testing agents to the tooth surface.

In the control group, RCT was performed after patient reported soft tissue signs of anaesthesia were achieved and a sham test was given. A sham or placebo test was performed by isolating and drying the tooth. Endo-Ice F was then sprayed for approximately 3 seconds, with the head of the spray directed about 2 feet away in the opposite direction of the cotton pellet. The cotton pellet remained at room temperature upon placement on the midfacial surface of the concerned tooth. Spraying was done outside the subjects view.

Standard RCT was rendered using rubber dam isolation, appropriate irrigants, cleaning and shaping of canals and gutta-percha fillings with sealer. If a root canal procedure took more than one visit, subjects were asked to participate only for the first visit when the pulpectomy took place.

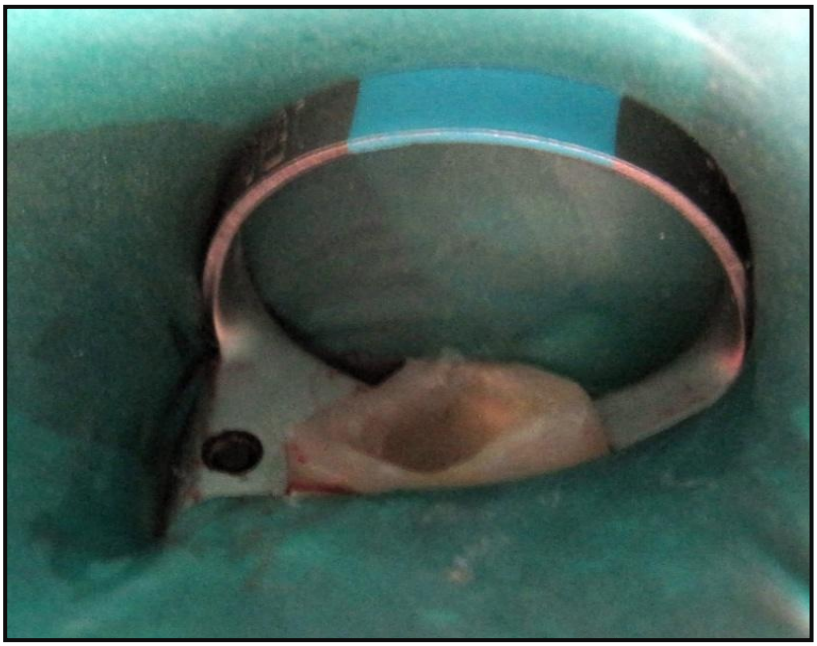

Fig. 6: Patient undergoing RCT

Subjects were asked to inform the clinician if they experienced any pain during the procedure. If pain was experienced, patients were asked to point to their level of pain on a visual analogue scale (VAS). The severity of the pain and the stage at which it occurred were recorded on the VAS form by the clinician. The stages of RCT were divided as follows: (i) before entering the pulp chamber, (ii) while entering the pulp chamber, (iii) extirpating the pulp and (iv) instrumenting the canal. Subjects experiencing pain more than once were asked to repeat the task of reporting severity as described above. The highest self reported pain score was used to represent the overall pain score experienced by the patient. More local anaesthetic was then given as deemed appropriate by the clinician.

S. No	AGE	SEX	TOOTH NO.	MEASURE OF LA ADMINISTERED (ml)	POST-LA		PAIN DURING PROCEDURE				OVERALL PAIN SCORE
					COLD TEST	*SOFT TISSUE SIGNS*	*(1)*	*(2)*	*(3)*	*(4)*	

Fig. 7: Data documentation sheet used for the test arm

S. No	AGE	SEX	TOOTH NO.	MEASURE OF LA ADMINISTERED (ml)	POST-LA		PAIN DURING PROCEDURE				OVERALL PAIN SCORE
					SHAM TEST	*SOFT TISSUE SIGNS*	*(1)*	*(2)*	*(3)*	*(4)*	

Fig. 8: Data documentation sheet used for the control arm.

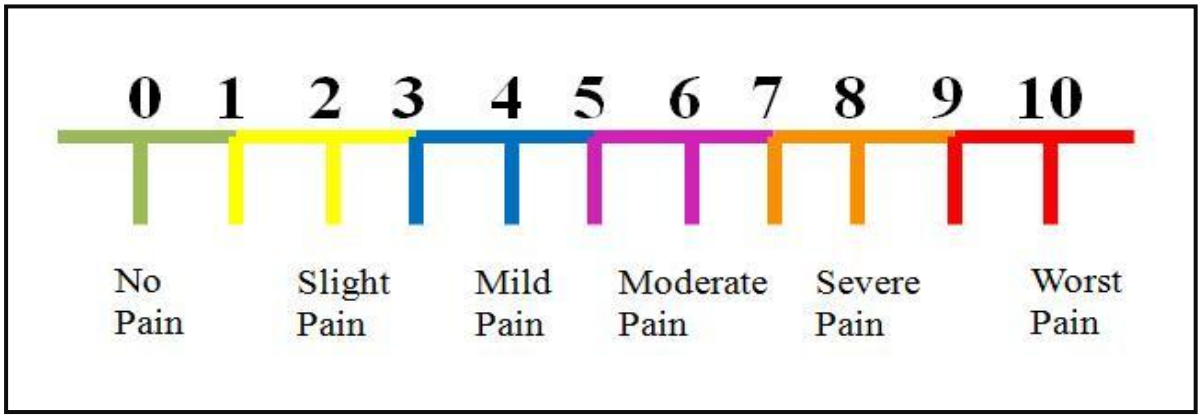

Fig. 9: Visual Analogue Scale

Table 1: Test of homogeneity for age between control and test arm group

AGE	GROUP	N	MEAN	STD. DEVIATION	t	LEVEL OF SINIFICANCE
	Control group	64	37.15	12.77	0.903	0.368
	Test group	64	35.14	12.46		

In the above table, the t value 0.903 for the mean difference in age of patients in the control arm and test arm is not significant (p< 0.368). The mean age of the subjects in the control arm and test arm groups were 37.15 and 35.14 respectively. As there is no significant differences in the age between the control arm and test arm, homogeneity was maintained in the study with respect to this variable.

Graph 1: Bar diagram representing homogeneity for age between control and test arm group

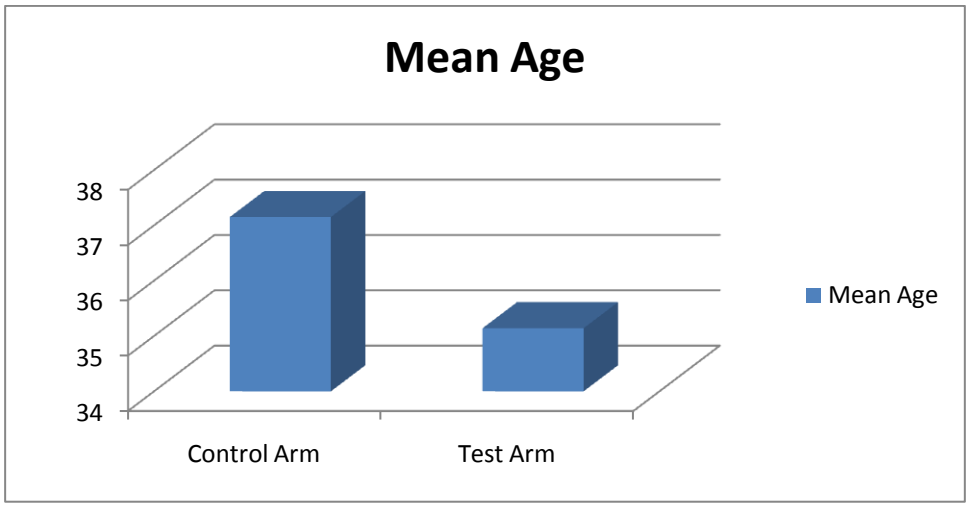

Table 2: Test of homogeneity for gender between control and test arm group

GENDER		GROUP		TOTAL
		Control arm	Test arm	
FEMALE	Count	29	26	55
	% within gender	52.7%	47.3%	100.0%
	% within group	45.3%	40.6%	45.0%
MALE	Count	35	38	73
	% within gender	47.9%	52.1%	100.0%
	% within group	54.7%	59.4%	57.0%
TOTAL	Count	64	64	128
	% within gender	50.0%	50.0%	100.0%
	% within group	100.0%	100.0%	100.0%

Within the control group 45.3% (29/64) of the subjects were female and 54.7% (35/64) were male. Within the test group 40.6% (26/64) of the subjects were female and 59.4% (38/64) were males. Out of the total number of females, 52.7% (29/55) of them were allotted to the control arm and 47.3% (26/55) were allotted to the test arm. Out of the total number of male patients, 47.9% (35/73) of them were allotted to the control arm and 52.1% (38/73) were allotted to the test arm.

Graph 2: Bar diagram representing homogeneity of gender between control and test arm group

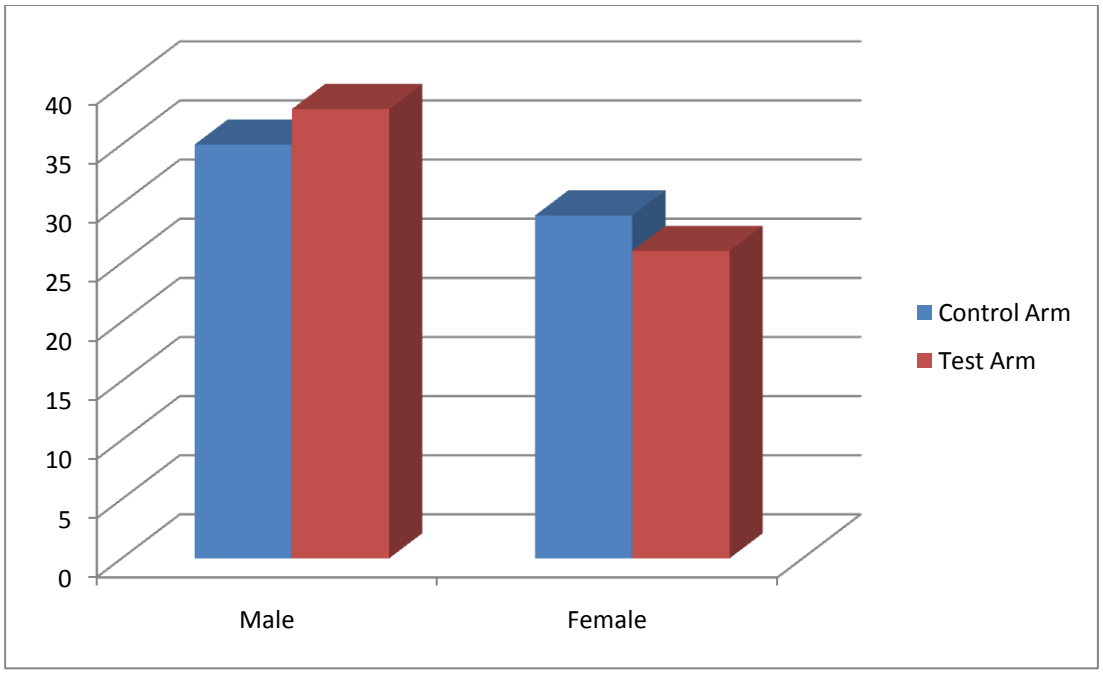

Table 3: Chi-Square Test for the association between gender and group (test arm and control arm)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	0.287[a]	1	0.592

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 27.50

In the above table the χ^2 value 0.287 for the association between gender and group (test arm and control arm) is not significant ($p<0.592$). It can be inferred that equal distribution of gender were maintained in the control arm and test arm groups before commencement of procedures. Thus homogeneity was maintained during the study with respect to this variable.

Table 4: Test for homogeneity in the position of tooth between control and test arm group

POSITION OF TOOTH		GROUP		TOTAL
		Control arm	Test arm	
Maxillary	Count	32	41	73
	% within position of tooth	43.8%	56.2%	100.0%
	% within group	50.0%	64.1%	57.0%
Mandibular	Count	32	23	55
	% within position of tooth	58.2%	41.8%	100.0%
	% within group	50.0%	35.9%	43.0%
TOTAL	Count	64	64	128
	% within position of tooth	50.0%	50.0%	100.0%
	% within group	100.0%	100.0%	100.0%

In the control arm 50% (32/64) of teeth were from the maxillary arch and 50% (32/64) from the mandibular arch. In the test arm 64.1% (41/64) of teeth were from the maxillary arch and 35.9% (23/64) from the mandibular arch. Out of the total number of maxillary teeth, 43.8% (32/73) was allotted to the control arm and 56.2% (41/73) to the test arm. From all the available mandibular teeth, 58.2% (32/55) were allotted to the control arm and 41.8% (23/55) were allotted to the test arm.

Table 5: Chi-Square Test for the association between position of tooth and group (test arm and control arm)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.582[a]	1	0.108

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 27.50

In the above table the χ^2 value 2.582 for the association between position of tooth and group (test arm and control arm) is not significant (p<0.108). It can be inferred that equal distribution of teeth from both arches were maintained in the control arm and test arm groups before commencement of procedures. Thus homogeneity was maintained during the study with respect to this variable.

Table 6: Mean difference in the initial measure of L.A between control arm and test arm group

	GROUP	N	MEAN	STD. DEVIATION	t	LEVEL OF SINIFICANCE
INITIAL MEASURE OF L.A ADMINISTERED	Control group	64	2.32	0.507	0.464	0.643
	Test group	64	2.28	0.482		

In the above table, the t value 0.464 for the mean difference in the initial measure of local anaesthetic administered to patients in the control arm and test arm is not significant (p<

0.643). The mean measure of local anaesthetic administered in the control arm and test arm groups were 2.32 and 2.28 respectively. It is evident from the results that the initial measure of LA administered to the control and test group were of equal quantity.

Table 7: Mean difference in the second phase of L.A administration between control arm and test arm group

	GROUP	N	MEAN	STD. DEVIATION	t	LEVEL OF SINIFICANCE
MEASURE OF L.A ADMINISTERED (2^{nd})	Control group	64	0.0563	0.316	3.941	0.001
	Test group	64	0.4906	0.823		

In the above table, the t value 3.94 for the mean difference in the 2^{nd} measure of local anaesthetic administered to patients in the control arm and test arm is significant ($p< 0.001$). The mean measure of local anaesthetic administered in the control arm and test arm groups were 0.0563 and 0.4906 respectively. The results reveal that as the patients in the test arm responded positively to cold test they required the administration of additional amount of local anaesthetic during the second phase of L.A administration, when compared to the control group.

Table 8: Mean difference in the third phase of L.A administration between control arm and test arm group

MEASURE OF L.A ADMINISTERED (3^{rd})	GROUP	N	MEAN	STD. DEVIATION	t	LEVEL OF SINIFICANCE
	Control group	64	0.000	0.000	2.276	0.025
	Test group	64	0.0750	0.264		

In the above table, the t value 2.276 for the mean difference in the 3^{rd} measure of local anaesthetic administered to patients in the control arm and test arm is significant ($p< 0.025$). The mean measure of local anaesthetic administered in the control arm and test arm groups were 0.00 and 0.075 respectively. The results confirmed that as the patients in the test arm responded positively to cold test they required the administration of additional amount of local anaesthetic during the third phase of L.A administration, when compared to the control group.

Table 9: Distribution of patients experiencing pain in control arm and test arm group

PAIN		GROUP		TOTAL
		Control arm	Test arm	
ABSENT	Count	41	59	100
	% within pain	41.0%	59.0%	100.0%
	% within group	64.1%	92.2%	78.1%
PRESENT	Count	23	5	28
	% within pain	82.1%	17.9%	100.0%
	% within group	35.9%	7.8%	21.9%
TOTAL	Count	64	64	128
	% within pain	50.0%	50.0%	100.0%
	% within group	100.0%	100.0%	100.0%

The above table shows that 64.1% (41/64) patients did not experience pain in the control group whereas 92.2% (59/64) did not experience pain in the test group. 35.9% (23/64) and 7.8% (5/64) patients experienced pain in the control arm and test arm respectively. It is also clear from the table that out of the 100 patients, who did not report any pain, 41% (41/100) were from the control group and 59% (59/100) were from the test group. Also from the 28 patients who reported an incidence of pain 82.1% (23/28) were from the control group and 17.9% (5/28) were from the test group.

Graph 3: Bar diagram representing distribution of patients that experienced pain in control arm and test arm group

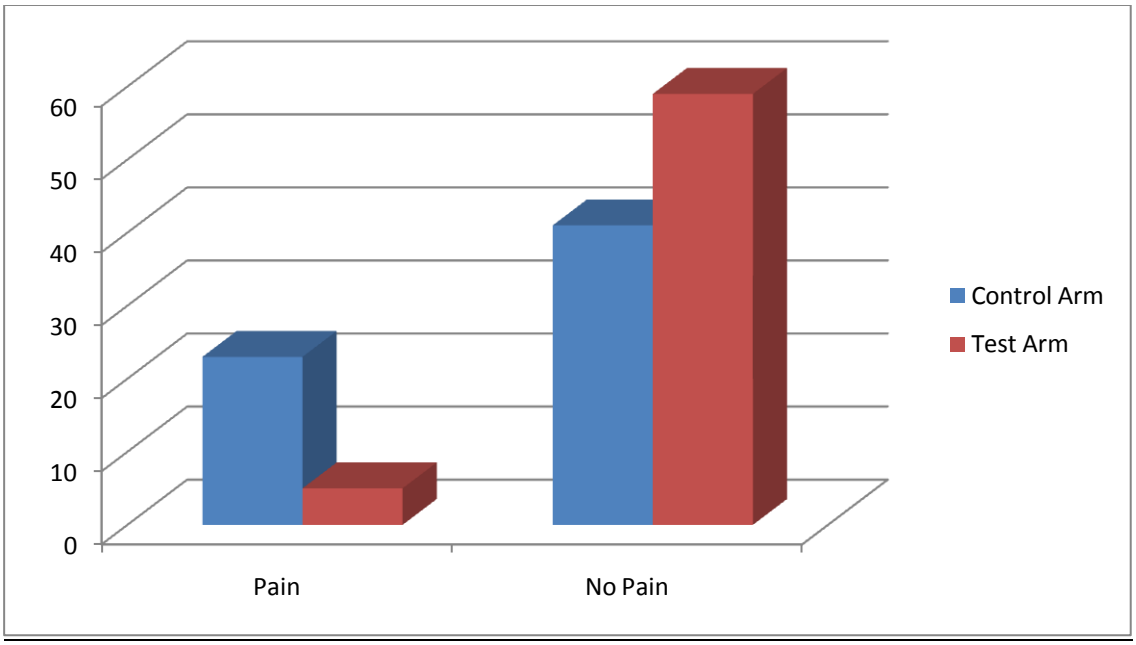

Table 10: Chi-Square Test for the association between pain experienced and group (test arm and control arm)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.811[a]	1	0.001

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 14.00

In the above table, the χ^2 value 14.81 for the association between pain experienced and group (test arm and control arm) is highly significant ($p<0.001$). It can be inferred that lesser number of patients from the test arm group experienced pain compared to the control arm group.

Table 11: Mean difference in the pain score between control arm and test arm group

	GROUP	N	MEAN	STD. DEVIATION	t	LEVEL OF SINIFICANCE
OVERALL PAIN SCORE	Control group	64	1.14	1.876	4.156	0.001
	Test group	64	0.13	0.549		

In the above table, the t value 4.156 for the mean difference of pain experienced by patients in the control arm and test arm is significant ($p < 0.001$). The mean pain score of the subjects in the control arm and test arm groups as elicited by the use of a visual analogue scale were 1.14 and 0.13 respectively. From the above result it is evident that the intensity of pain experienced by the patients in the test arm was markedly less when compared to the control group.

Graph 4: Bar diagram representing mean difference in the pain score between control arm and test arm group

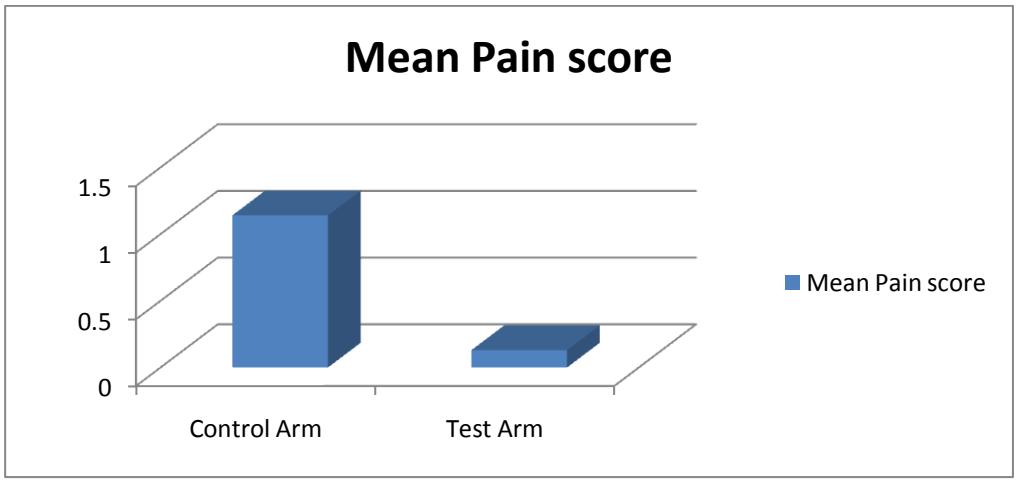

Table 12: Mean difference in pain experienced by patient based on position of tooth

	POSITION OF TOOTH	N	MEAN	STD. DEVIATION	t	LEVEL OF SINIFICANCE
PAIN	Maxillary	73	0.05	0.229	5.766	0.001
	Mandibular	55	0.44	0.501		

In the above table, the t value 5.766 for the mean difference of pain experienced by patients based on the position of tooth (Maxillary and Mandibular) is highly significant ($p < 0.001$). The mean pain score of the subjects in the maxillary group and mandibular group as elicited by the use of a visual analogue scale were 0.05 and 0.44 respectively. From the above result it is evident that there is a significantly higher probability of patients experiencing pain when mandibular teeth are considered for endodontic procedures because of the obvious difficulty of achieving pulpal analgesia in that arch.

One of the most important aspects of endodontic practice is the control or elimination of pain. The primary method of pain control in dentistry is injection of a local anaesthetic agent and the ultimate goal is complete analgesia. Various studies [1, 26, 27, 33] have tested the ability of anaesthetic agents and techniques to achieve complete analgesia. Some studies [26, 27] have used dental procedures as the test stimuli and relied on the patient's ability to interpret and report painful stimuli. However, dental procedures are difficult to standardize and this may create variability in the results. Pain perception and pain expression of an individual are results of complex interactions of many variables. Pain expression is not simply the result of a single noxious stimulus, but is affected by personal history variables, cultural history variables, and the meaning of the pain expression to the individual [19, 47].

Thermal and electrical vitality tests are widely used as pulp sensibility ascertaining aids to assess the status of the dental pulp. The functional integrity of the intradental sensory nerve fibres determines their ability to respond to stimulation and conduct impulses. Since nerve fibres of the pulp are relatively resistant to necrosis [13, 34], the diseased pulp may continue to respond to stimulation even when its other constituents have undergone degenerative changes. Failure of the sensory units to respond indicates that pulpal necrosis is far advanced or in this case that pulpal analgesia has been obtained.

Various studies [1, 33] have used the electric pulp tester as an instrument to evaluate anaesthesia. The standardization of stimulation, combined with fewer traumas as compared with dental procedures, created less variability in the patient's interpretation of stimulation [19] and therefore less variability in the results. The studies assumed that the teeth were anesthetized when they did not react to the maximum output of the electric pulp tester. This assumption was based on the work of **Bjorn** [4] who was the first investigator to correlate the lack of pain during operative and pulpectomy procedures with the obtainment of no response

to the maximum output of a pulp tester. The EPT is believed to cause ionic shifts within the dentin fluid, resulting in the localized depolarization of nerve membranes and the production of action potentials. Although the electric pulp test is commonly used to determine the vitality of pulps, it has several limitations. It may evoke a false-positive response when used to test nonvital teeth with large metallic restorations which are capable of conducting electrical impulses to the periodontal tissues and also from teeth with liquefaction necrosis of the pulp [12]. It has also been shown that the electric pulp test is not reliable in testing the vitality of young teeth regardless of whether they have an open or closed apex [14].

An alternative to the electric pulp test is assessment of pulp sensibility by applying a thermal stimulus to the tooth surface. Thermal tests involving cold as a stimulus use agents such as ethyl chloride, ice, carbon dioxide snow (dry ice), dichlorodifluoromethane (DDM), 1,1,1,2 tetrafluoroethane (1,1,1,2 TFE), and a blend of propane/butane/isobutene gas mixture stored in a pressurised canister. Of these, ethyl chloride and ice were initially the agents most commonly used in clinical practice and their use was recommended by several authors [9, 10, 51]. However, other authors later found ethyl chloride and ice tests to be unreliable [2, 12, 17]. According to **Ehrmann** [12] as well as **Schroeder** [45] carbon dioxide snow was the agent of choice in testing pulp sensibility as it was found to be reliable when used for testing teeth with metallic splints and temporary crowns [15] and teeth with immature apices [14]. Later, from the studies of **Fuss Z et al** [16] it was concluded that DDM was equally effective and in fact faster in evoking a response to pulp sensibility testing. Even after the low liquid temperature of -50°C (DDM) was raised to -26°C (1,1,1,2 TFE), due to reformulation of refrigerant sprays owing to environmental issues, these results were still reproducible [24].

The A-δ fibres are believed to be the neurons initially stimulated during electric and cold pulp testing procedures. **Naylor** [36] determined that for dentinal pain to be felt, the pulpodentinal junction must cool to 29°C. **Trowbridge et al** [48] concluded that the thermal

sensory response is not initiated by actual temperature changes occurring in the receptors but by hydrodynamic forces produced by temperature changes within the dentin. Stimulation must produce a rapid displacement of material within the tubules to stimulate a painful response. The findings of **Trowbridge et al** [48] are consistent with the hydrodynamic theory.

Clinically, following lip numbness, application of a cold refrigerant or the electric pulp tester can be used to test the tooth under treatment for pulpal anaesthesia prior to beginning of a clinical procedure [6, 11, 38]. Therefore, following an inferior alveolar nerve block and achieving lip numbness, we can now determine if the tooth is anaesthetised before starting treatment. Clinical studies of endodontics [8, 38] in patients with irreversible pulpitis have found success (mild or no pain upon endodontic access or initial instrumentation) with the inferior alveolar nerve block alone between 19% and 56% of the time. Therefore, these studies would indicate that anaesthesia is often difficult to achieve in irreversible pulpitis with only the inferior alveolar nerve block. There are a number of reasons that have been suggested as to why endodontic patients who are in pain and have pulpal pathosis have additional anaesthetic problems. They include:

1. The inferior alveolar nerve block does not always provide profound pulpal anaesthesia [20, 28, 49].
2. There is a theory that the lowered pH of inflamed tissue reduces the amount of the base form of anaesthetic to penetrate the nerve membrane. Consequently, there is less of the ionized form within the nerve to achieve anaesthesia. However, this explanation of local influences on the anaesthetic solution does not explain the mandibular molar with pulpitis, which is not readily blocked by an inferior alveolar injection administered at some distance from the area of inflammation. Therefore, it is difficult to correlate local pH changes with failure of the inferior alveolar nerve block.

3. Nerves arising from inflamed tissue have altered resting potentials and decreased excitability thresholds [5, 50]. Therefore, local anaesthetic agents do not prevent impulse transmission due to these lowered excitability thresholds.
4. Tetrodotoxin-resistant (TTX-R) class of sodium channels that have been shown to be resistant to the action of local anaesthetics [44]. A related factor is the increased expression of sodium channels in pulps diagnosed with irreversible pulpitis [46].
5. Finally, patients in pain are often apprehensive, which lowers their pain threshold.

In the present study, all patients were subjected to a cold test using propane/butane/isobutene gas mixture to confirm that the tooth had a definite response to cold. As reported by **Jones** [23], a cotton tip applicator would be relatively ineffective, indicating that a larger volume of cotton to hold more refrigerant spray liquid is important. This was the reasoning behind selection of a large #2 size cotton pellet as the carrier for application of the refrigerant spray to the teeth. The post graduate student performing the study considered the first 64 patients who came to the dental OP fulfilling the inclusion and exclusion criteria as the test arm group and the subsequent 64 patients as the control arm group, thus effectively randomizing the patients into either arm.

After the baseline test, the patients were aware as to what to expect from a cold test. They were informed about a cold test going to be conducted after delivery of anaesthesia. They were also made aware that it would be natural not to feel the same initial sensation they felt before administration of the local anaesthetic agent. The patients were then subjected to the cold test or the sham test without informing them as to what test is being conducted. After eliciting a negative response to cold test in the test arm and a negative response to soft tissue

signs in the control arm, the patient was directed to a clinician who was kept unaware of the patients randomization arm thus effectively making this a double blinded, two arm, placebo controlled study.

Obtaining anaesthesia in teeth with symptoms of irreversible pulpitis can be more difficult than achieving anaesthesia in teeth without symptoms. **Dreven et al** [11] reported that patients with normal or asymptomatic teeth did not experience pain during endodontic therapy, compared to subjects with irreversible pulpitis, who felt pain 27% of the time. Inflamed pulp tissues have been shown to have a decreased pain threshold, likely as a result of increased vascular permeability and inflammatory chemical mediators [5]. Owing to these reasons, it was decided that only a tooth demonstrating irreversible pulpitis was to be considered for this study. Irreversible pulpitis was defined as a tooth with a history of pain to cold and hot stimuli with lingering pain and / or spontaneous pain.

In earlier studies [8, 11, 21] patient initiated pain reports were used which may have caused a bias because of the reluctance of shy patients to report pain. So in this study the protocol was designed to assess pain at certain time intervals during treatment to help draw out reluctant subjects.

In our study, the student's t test was used as a statistical tool to evaluate differences between age and initial measure of local anaesthetic administered (Table 1 and Table 6) in patients from the test arm and control arm. The χ^2 test was used to assess the same with regard to gender and position of tooth in the masticatory arches (Table3 and Table 5) in either group. The relevance of these tests was to demonstrate the homogeneity between the test arm and control arm thus eliminating bias.

The results of our study show that the percentage of patients who experienced pain during endodontic treatment in the test arm (7.8%) was less than those in the control arm (35.9%) and these results were highly significant ($p < 0.001$) [Table 9 and Table 10]. The

student's t test depicting mean difference in pain score between control arm and test arm group (Table 11) shows that, the patients who had pain in the test arm had to endure a significantly lower degree of pain compared to those patients in the control arm and these readings were highly significant ($p < 0.001$). Student's t tests (Table 7 and Table 8) show that more amount of local anaesthesia was delivered in the test group during the second and third phase of local anaesthetic administration. These and the earlier results from table 11 can probably be attributed to the fact that patients in the test arm responded positively to the cold test even after the initial administration of the local anaesthetic, which warranted additional injections of the local anaesthetic agent in these patients. Another interesting finding seen from the evaluation of results (Table 12) is the fact that there was a higher probability of patients experiencing pain when the tooth in question belonged to the mandibular arch. The results showed that the odds of experiencing pain for mandibular teeth were five times greater than for maxillary teeth, which is in agreement with previous studies [8, 21].

Time needed for treatment was not recorded in this study. Clinicians in this study were both post graduate students and attending endodontists treating patients from all walks of life and teeth with varying degrees of complication. Hence, the time needed for the pulpectomy may have varied depending on the clinician, the patient, and the tooth in question. This could have affected the outcome, as the anaesthetic effect decreases over time. Future studies could consider time needed for treatment as a variable of interest to control for potential biases between operators, patients who may be hard to manage, and teeth that may be difficult to isolate or treat for other reasons

The findings of this study corroborate previous studies which suggest superior ability to determine pulpal anaesthesia through the use of pulp vitality testers [8, 11, 16, 21]. For patients with teeth presenting with pulpitis, 7.8% (5/64) of the subjects who had symptoms of pulpitis and achieved a negative cold response (test group) felt pain. This was lower than in three

previous studies that reported approximately 27 to 31% of their patients felt pain [11, 38, 42]. This discrepancy may result from the fact that the method used to assess pulpal anaesthesia in these studies was the electric pulp tester, which has been shown to be less sensitive and specific with a lower positive predictive value (PPV) and negative predictive value (NPV) than the cold test [41]. The percentage of test patients experiencing pain in the present study was also lower than the 18% which was observed in a recent study by **Hsiao-Wu et al** [21] using 1,1,1,2 tetrafluoroethane (-26°C) as a cold test stimulus. This variation in result could be because of the difference in temperature of 1,1,1,2 tetrafluoroethane (Green Endo-Ice) and the propane/butane/isobutene gas mixture (Endo-Ice F) which had a temperature of -26°C and -50°C respectively. The figures obtained were on par with another study by **Cohen et al** [8] which used dichlorodifluoromethane (-50°C) as the cold stimulus and reported an incidence of 8% in pain. This probably was because the Endo-Ice F and DDM shared the same low liquid temperature of -50°C.

Through this randomized, double blinded, placebo-controlled clinical trial, it was clearly demonstrated that the cold test is a significantly better indicator of pulpal anaesthesia compared with the current standard of care of using soft tissue signs alone. From the findings of this study, the use of cold test to assess pulpal anaesthesia can be strongly advocated. The cold test is easy to use, inexpensive, quick to perform, and well tolerated by most patients. There are also no reported detrimental effects to the pulp with repeated use of thermal pulp vitality tests [43]. This test can be especially helpful when treating mandibular teeth and teeth with pulpitis or when caring for patients who are apprehensive about experiencing pain during dental treatment because it can demonstrate the effectiveness of the anaesthesia.

This study evaluated if the Endo-Ice F® would measure clinical analgesia in teeth with the clinical diagnosis of irreversible pulpitis. Following vital baseline pulp test readings, a pre-determined measure of 2% lidocaine with epinephrine was administered by block or infiltration. The progression of analgesia in the test arm was measured with the Endo-Ice F until a negative response was elicited or if a response was felt, additional pre-measured doses of local anaesthetic was administered. In the control arm, progression of analgesia was measured using only soft tissue signs and mucosal sticks. Clinical analgesia was then measured by performing an endodontic procedure. The results of this study showed that in teeth with irreversible pulpitis; clinical analgesia was achieved 92.8% of the time, when a patient showed negative response to cold test using the Endo-Ice F after administration of a local anaesthetic. Supplemental injections were sometimes required to achieve this negative response.

It can be concluded that until such a time as the existence of an agent or technique that can give us a 100% guarantee as to the pulpal analgesia experienced by a patient about to undergo endodontic treatment; achieving a negative response to the cold test prior to endodontic therapy should become the standard of care over soft tissue signs alone. Moreover, for teeth that are non-responsive to cold at base line, using the cold test to assess profound anaesthesia in the working area by testing adjacent teeth would be a good suggestion. Often teeth that are non-responsive to a pulp vitality test may still have reactive pulpal tissue. Ensuring that the working area has profound anaesthesia can prevent patients from experiencing unnecessary pain and positively affect the patients overall experience.

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